NAEH Workshop Summary

The Oak Ridge Center for Advanced Studies (ORCAS) and the U.S. Environmental Protection Agency (EPA) cosponsored a workshop entitled "Nanotechnology applications in environmental health: Big plans for little particles" at the EPA Research Triangle Park campus in Durham, North Carolina, on April 20, 2006. The full-day meeting convened top nanotechnologists and environmental and ecosystems health researchers for a discussion about the use of nanotechnology, particularly nanosensors, in environmental health, human exposure research, and ecosystems research. The workshop was novel in bringing together environmental health and product discovery researchers. The purpose of the workshop was to provide a forum for nanotechnology researchers to learn about needs and concerns, and for those working with sensing applications to learn about nanotechnology as a tool.

For the EPA, nanotechnology presents both opportunities and concerns. On one hand, nanotechnology can be used to detect, monitor, and clean up environmental contaminants. On the other, nanotechnology poses a challenge to the EPA as a regulatory agency. EPA must address the unintended consequences of nanomaterials—before they occur—with few data presently available on the health and ecological effects of these materials. An EPA white paper on nanotechnology research applications and implications is available in draft form. Because nanotechnology has the potential to affect society in profound ways, for better and worse, nanotechnology is also an ORCAS priority. Nanosensors, and sensors with nano-components, are increasingly making the transition from bench development to field use. As such, discussion of potential risks and rewards is timely.

Speakers

Dr. Paul Gilman introduced ORCAS and explained the purpose of the meeting. Dr. Lawrence Reiter provided an overview of nanotechnology research at the EPA. The EPA has funded 70 different nanotechnology grants since 2001. EPA's nanotechnology research program is still under development, but its primary aim is to advance an understanding of nanotechnology impacts. A smaller, though important, subset of EPA programming focuses on exploring nanotechnology applications for sensing and monitoring. The agency's FY07 budget request includes a $4 million dollar increase (an approximate doubling) for nanotechnology research.

Dr. Clayton Teague explained the purpose and activities of the National Nanotechnology Initiative (NNI) and his office, the National Nanotechnology Coordinating Office. He provided an overview of NNI member work applicable to sensing, described the landscape of federal funding for nanotechnology research, and speculated about future research directions.

Dr. Tuan Vo-Dinh described the value of using nanosensors to explore interactions within living cells. He also explained the Raman effect and discussed plasmonics and Surface-enhanced Raman Scattering (SERS) applications for homeland security, life sciences, and biomedicine.

Panel 1

Dr. David Balshaw (National Institute of Environmental Health Sciences) presented the NIEHS agenda for nanotechnology research. In particular, NIEHS goals are to develop sensor technologies and tools to support research and remediation, identify determinants of biological compatibility or toxicity, and evaluate implications of nanotechnology use and exposure.

Dr. James Bonner (CIIT) presented information about his work on the inflammatory and the fibrogenic potential of carbon nanotubes.

Dr. Meng-Dawn Cheng (Oak Ridge National Laboratory) described the effects of ozone on nanomaterials used for making nanosensors, and the cellular responses as results of exposure to the raw and ozone-modified nanomaterials.

Dr. Kevin Dreher (EPA) spoke about needs and uncertainties regarding the health effects of manufactured nanomaterials. He also spoke about the potential value of nanotechnology applications, including as environmental sensors, biological sensors, and as remediation and intervention devices.

Dr. Roger Narayan (Joint Department of Biomedical Engineering, North Carolina State University and University of North Carolina) talked about the toxicity and potential health effects of nanomaterials, particularly carbon nanotubes, but also about the potential value of "diamond-like" carbon films in medical applications.

Panel 2

Dr. Elaine Cohen Hubal (EPA) talked about exposure monitoring challenges faced by the EPA's Office of Research and Development. These challenges include the need to monitor and assess exposures from multiple sources by multiple pathways and routes. There is also a need to monitor exposure to mixtures. Biomarkers are required to link external exposure with internal dose. She described ways in which nanoscale capabilities could help EPA address these challenges—by enabling real-time, individual-level sensing, for instance.

Dr. Somenath Mitra (Department of Chemistry and Environmental Science, New Jersey Institute of Technology) described the value of single-walled carbon nanotubes as sensors and described some of the manufacturing and environmental health obstacles to their use.

Dr. Michael Strano (Department of Chemical and Biomolecular Engineering and the Center for Nanoscale Science and Technology, University of Illinois Urbana-Champaign) discussed application of DNA-wrapped carbon nanotubes as sensors in living cells. Recent research in his laboratory opens the door to new types of optical sensors and biomarkers that exploit the unique properties of particles in living systems.

Dr. Thomas Thundat (ORNL) talked about the advantages of micro- and nano-cantilever arrays, their selectivity and specificity, and examples of their detection applications. Examples of applications include detection of biotoxins, nerve gas, CrO4 ions, and methyl mercury. He identified "getting the signal out" as the primary impediment to their use.

Dr. Brenda Weis (NIEHS) described NIEHS exposure data needs and suggested that nanosensors may help NIEHS in the collection of personal environment and biological measurement data. She also explained the institute's new program in exposure research.

Panel 3

Dr. Jim Davidson (Electrical Engineering and Materials Science and Engineering, Vanderbilt University) spoke about the Advanced Carbon Nanotechnology Program and about the value of nano-diamond materials for sensing applications.

Dr. Zhihua (Tina) Fan (Exposure Measurement and Assessment Division, Environmental and Occupational Health Sciences Institute, University of Medicine and Dentistry of New Jersey, Rutgers University) described the current state of her work in monitoring exposure to particulate matter and suggested that nano-scale sensing technology would be useful as a way of making individual-level exposure assessment more rapid and less cumbersome for the person whose exposure is being assessed.

Mr. Miguel Rodriguez (Chemical Sciences Division, ORNL) spoke about AquaSentinel, a real-time detection product developed at ORNL and successfully commercialized for environmental sensing applications. AquaSentinel uses microscopic algae as biosensors for the detection of waterborne agents.

Dr. Nora Savage (EPA) presented her vision for the future of individual-level sensing and discussed EPA/NCER work. A Web-based publication history is in development and the first three-year STAR grant cycle is coming to a conclusion and getting to the point that value-added can be determined. There will be a meeting in October of this year to present results of applications research. NCER is working with other federal agencies to determine ways to leverage funds for this research area.

Dr. Richard Zepp (EPA) described the current state of nanosensor technology for ecosystem applications and discussed possible limitations of nanosensors in environmental applications.

Discussion

Reducing the size and cost of sensing devices improves field measurement capability. These qualities are desirable from an exposure measurement perspective. But nanosensors must be proven to be valid, reliable tools.

- Are nanosensors sufficiently discriminating?
  - Does a local sample represent the entire area of interest? Have to worry about mixing characteristics of the system. Transport effects influence results. Characteristics of the system and materials that interfere or compete with bacteria for absorption onto the sensor can also be factors, for example.
- Is it time to move beyond laboratory studies and begin mimicking environmental conditions, moving into the field?
- Interoperability and comparisons from one laboratory to another are key concerns. Need to be able to replicate nanosensor products.

Nanomaterial quality-control is a concern.

- There is inconsistency between batches of manufactured nanotech products.
- What are the metrics? Are we far enough along in the discovery process to apply standard validation paradigms?
  - Higher levels of reliability and reproducibility of results are needed as progress is made.
  - NIST is looking at the issue of providing well-characterized, standardized materials because there is variability from batch to batch—looking to do this very soon.
  - One problem is coming to agreement on what measurements need to do. ISO standards activities: what are standard techniques that everyone accepts for characterizing the purity of a nanotube sample? A 90% pure carbon nanotube sample is considered to be a very pure, premium sample.
  - It doesn't make sense to use traditional toxicology methods for testing each new nanoparticle. There is a need to develop a more efficient strategy, different than one for characterizing chemicals.
  - U.S. is looking at safety issues, but many parts of world aren't (or aren't to the same extent). These places may ultimately wind up being key manufacturers. There is a need to consider issues globally. U.S. safety programs seem most robust, but there is still a lot of catching up to do within health and safety realm for these materials.

       o EPA (and the European Community too) is working to develop a stewardship program to get toxicology test and safety information from manufacturing companies.

Are there now nanosensors that are available for commercial use and how would we learn about them?

- Sensors that have nanomaterial components, like Chlorophyll A systems, are available and are being used. Nano-based sensors for bacteria are also available. Sensors for nitrogen are at an earlier stage of development, are micro-arrays to do this.

Are we ready to engage other sensor communities to find common ground?

- For example, GEOSS (Global Earth Observation System of Systems) is developing internationally. It is an observation-oriented program with a human and ecosystems health focus. Could GEOSS benefit from nanosenors programming?

Dialogue between people working in nanotechnology development and those looking to nanotechnology for solutions to some of the technical problems that they're dealing with is valuable.

- Corrective action considerations need to inform sensor technology. Need to think of what will come from the sensor first, rather than developing the technology without regard for its intended use.
- Dialogue should continue. What are the next-steps?

Next-steps

Workshop participants suggested the following next-steps and needs:

Interest in learning more about potential applications for exposure monitoring was significant.

A more focused workshop (or a series of workshops) on topics such as organic nano-scale sensors and/or chemistry opportunities is needed.

NNI subcommittee participants have been working on the development of a research needs document. The document is intended to provide advice to Congress, and is intended to be useful to program managers, researchers, and workers in the field. The document will be available some time this summer. Its evolution will be an iterative process. The nanotechnology community can have concrete input in revisions and additions to this document.